FIELD GUIDE TO "A" MOUNTAIN AND DESCRIPTION OF SURROUNDING REGION, PIMA COUNTY, ARIZONA

by

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Introduction

Sentinel Peak Park, also known as “A” Mountain, is an ideal location to see a variety of volcanic rocks and associated sedimentary rocks, to observe a panoramic view of the Tucson metropolitan area, and to survey the surrounding region. Sentinel Peak’s elevation is almost 2,900 feet, and stands nearly 550 feet above the adjacent Santa Cruz River flood plain. It is located in the southeastern Tucson Mountains adjacent to the Santa Cruz River and just west of downtown Tucson. The drive to the summit of “A” Mountain extends across a layered sequence of volcanic and sedimentary rocks well exposed in roadcuts. Ranges that surround the Tucson Basin are all clearly visible from the summit of “A” Mountain if weather, natural haze, or air pollution are not a problem. This field trip surveys the geology of these ranges and the geologic relationships between the ranges and the Tucson basin.

Directions

There is convenient street access by turning south on Cuesta Avenue off of Congress Street. Cuesta Avenue becomes Sentinel Peak Road (Fig. 1). A gate at the base of the loop drive is open only during established and posted hours for the park. Please note that the climb and descent around the perimeter of “A” Mountain is by a one-way paved road that does not have guard rails. While passengers can view the nearly horizontal layers of rock of Sentinel Peak, and enjoy a splendid regional panorama during the drive to the parking area, drivers will need to be cautious and attentive to driving. Most of the regional features described can be seen from the parking area. However, accessible trails lead to the crest of “A” Mountain where a nearly 360^{o} view of the Tucson basin and surrounding ranges is visible. There are no restroom facilities or water fountains available.

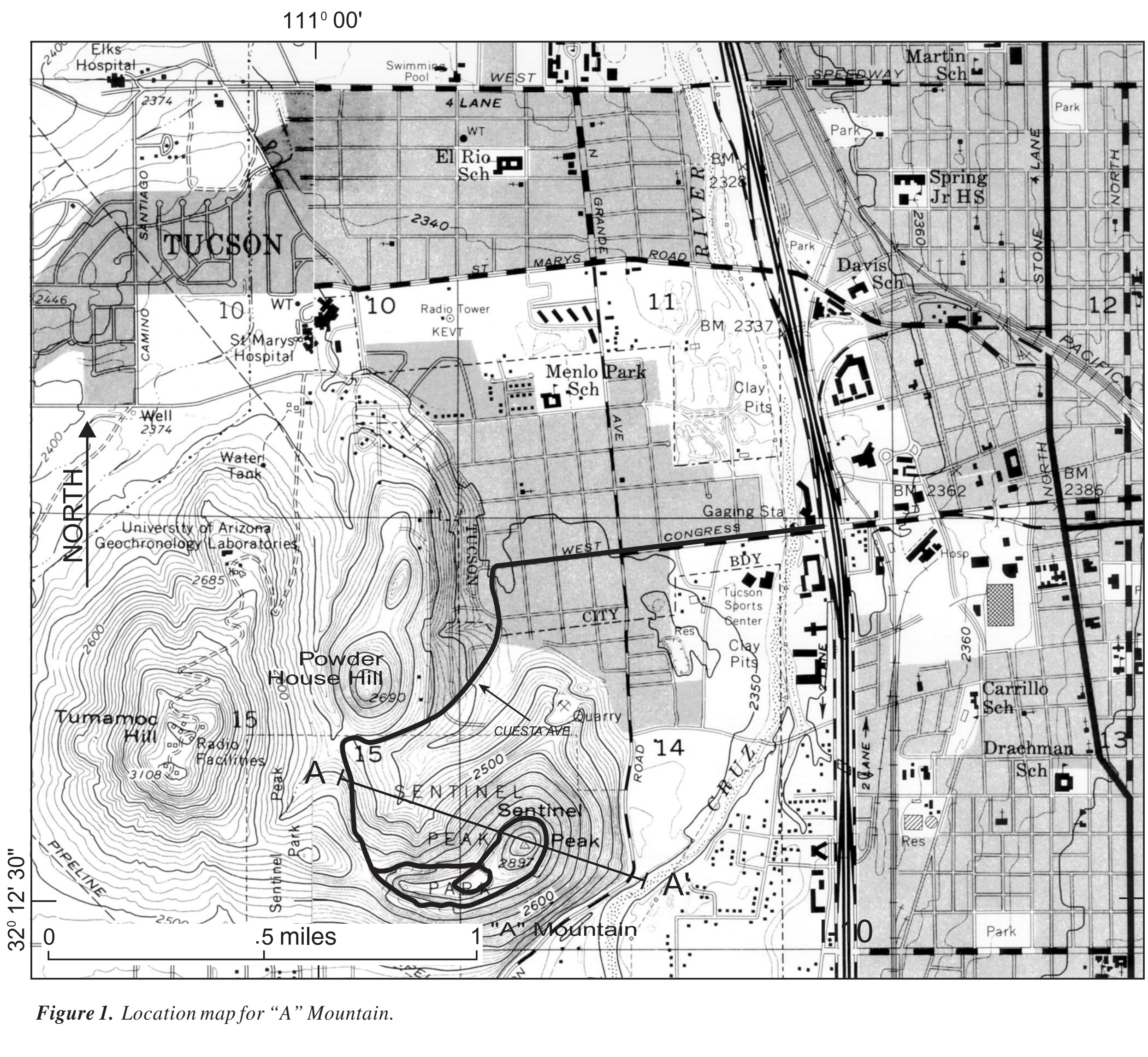


Figure 1. *Location map for “A” Mountain.*

Geologic Overview

"A" Mountain, Tumamoc Hill immediately to the west, and Powder House Hill, between the two to the north, consist of the same sequence of rock units. They tell a story of volcanic activity interspersed with periods of erosion and deposition of sediments by water. The ascending circular drive to the parking area on "A" Mountain passes upward through a series of progressively younger rocks.

Popular misconceptions are that "A" Mountain is an extinct volcano and that the "crater" at the base of the hill on the northeast side is the result of a meteor impact. Although it has the appearance of being a symmetrical volcano, the shape of "A" Mountain is the result of gradual weathering and erosion over millions of years. Although weathering and erosion are very slow and generally not noticeable, they are still actively modifying "A" Mountain. The abundance of rock fragments covering the surface of the mountain are evidence of this continuing process. Weathering and gravity will gradually break up and transport these fragments to the flat land below. There are, however, occasional episodes of exceptionally heavy rain that can cause pulses of more rapid weathering and erosion. Averaged over decades or centuries the weathering and erosion processes appear constant and steady. It is correct to assume that "A" Mountain is volcanic in origin, but it is not a volcano. The crater-like feature at the base of "A" Mountain is actually an inactive quarry where volcanic rock was used in local construction.

Geologic Features

In layered sequences of sedimentary or volcanic rocks, younger rocks overlie older rocks. This is the case with the rock units of "A" Mountain (Fig. 2). The rocks at the base of the drive (at the gate entrance) consist of a dark basalt. The basalt solidified from molten basaltic lava. The lava originally squeezed upward through the earth's crust via fractures and pipe-like conduits and then flowed downhill over the Earth's surface. The basalt flows are overlain by a sedimentary rock called **conglomerate** that was deposited on the lower basalt. It consists of loosely cemented pebbles derived from the underlying basalt and other rock types in the vicinity exposed at that time. These rock fragments were transported and deposited by moving water. Above the conglomerate are light gray and tan volcanic ash layers called **tuff**. These were formed from the accumulation and compaction of fine-grained volcanic rock fragments known as "volcanic ash" that fell to the ground from nearby eruptions. These tuff beds are approximately 26.5 to 27.5 million years

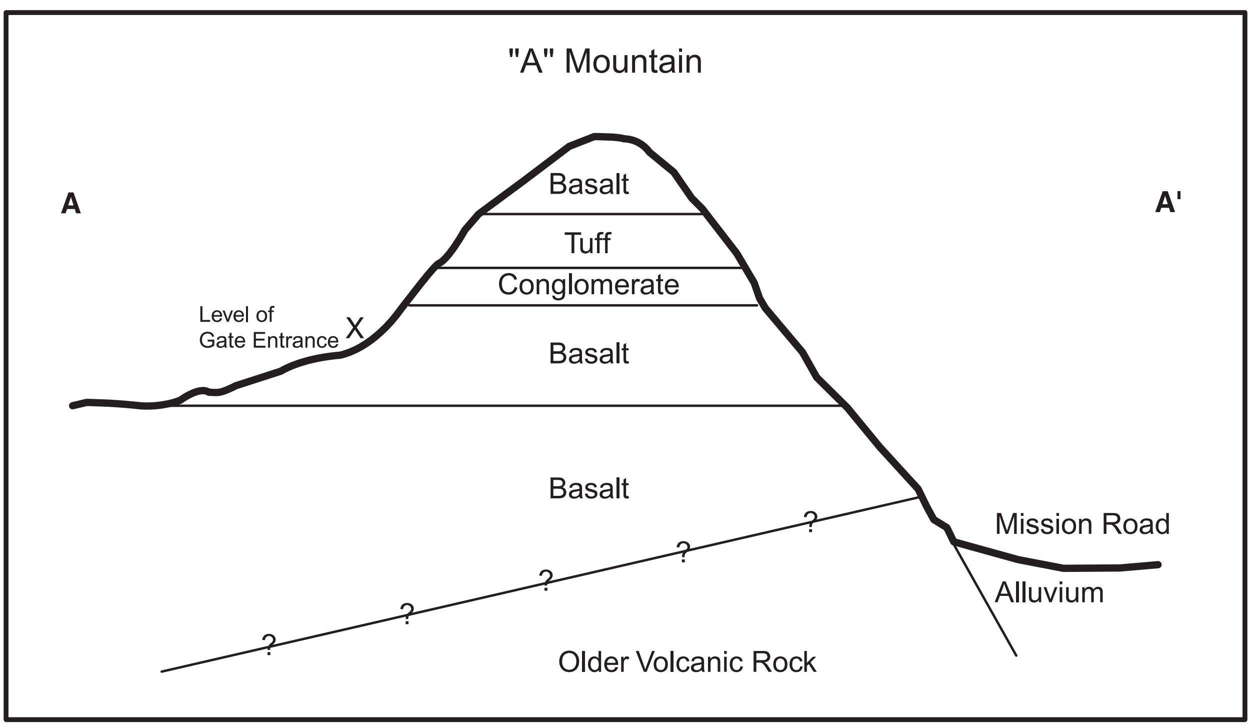


Figure 2. *Generalized cross section showing layered sequence of rocks through "A" Mountain. Refer to Figure 1 for location of cross section (drawing not to scale).*

old. Capping this entire sequence of rocks are more basalt flows. It is on these upper basalt flows that the "A" of "A" Mountain is maintained. The upper part of the sequence of layered volcanic and sedimentary rocks at "A" Mountain is nearly horizontal, and has not been tilted by movement on earthquake faults as have rocks lower in the sequence.

The thin white coating that is visible on some of the rock surfaces is called **caliche** (cal-lee-chee). It is calcium carbonate, the same chemical composition as limestone and marble, and forms near the surface as a result of evaporation of rain water. Caliche can be especially prevalent in arid environments where there are rapid evaporation rates.

VIEW OF SURROUNDING REGION FROM "A" MOUNTAIN

Introduction

The surrounding expanse viewed from "A" Mountain lies within the **Basin and Range geologic province**. The Basin and Range province consists of an alternating sequence of generally elongate mountain ranges separated by basins that have filled with as much as several thousand feet of sediment consisting of clay, silt, sand, gravel, and evaporites. Evaporites are a group of minerals, such as salt and gypsum, formed by chemical precipitation in evaporating, shallow lakes of the geologic past and are now buried in the basin. It is an extensive region that includes southern and western Arizona as well as parts of adjacent states and all of Nevada. In Arizona the population centers and the majority of agriculture production are located within the basins of the Basin and Range province (Fig. 3). The naturalist Aldo Leopold poetically described the Basin and Range province of southern Arizona as "mountain islands in a desert sea." "A" Mountain is a convenient location to observe the Tucson basin and surrounding mountains

Geologic Overview

The Tucson basin is the northern portion of a greater area called the **Santa Cruz basin**. It is bounded on the north and northeast by the Santa Catalina and Rincon Mountains, on the east and southeast by the Empire and Santa Rita Mountains, on the southwest and west by the Atascosa, Tumacacori, and Sierrita Mountains, and on the northwest by the Tucson Mountains (Fig. 4). These ranges consist of a great variety of rock types of various ages. The thickest section of sediment in the

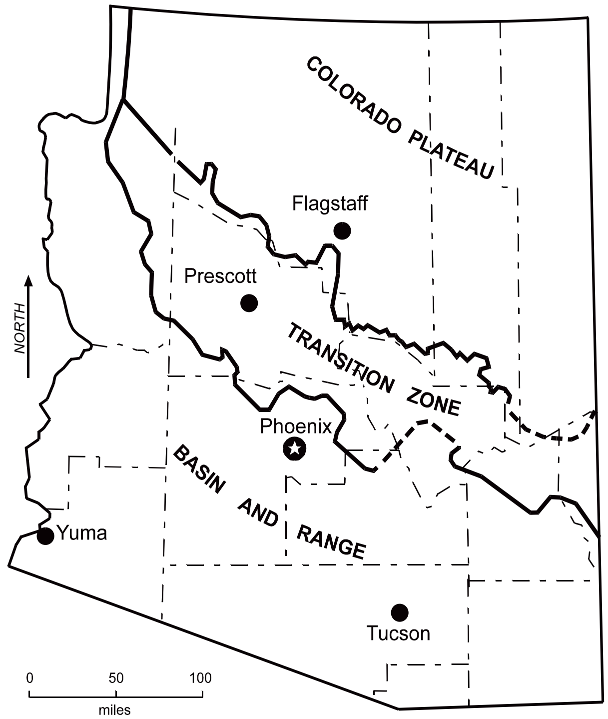


Figure 3. Map of Arizona showing geologic provinces and major cities.

bathtub-shaped Tucson basin lies southeast of the Tucson metropolitan area where the basin contains approximately 7,500 feet of silt, sand, and gravel. This material is collectively called **basin fill**.

It is appropriate to differentiate the terms basin and valley. A **basin** is a topographic depression that is or has been a center of sediment deposition. A **valley** is a low area that may or may not be a center of sediment deposition.

The present configuration of the Tucson basin and surrounding mountain region is largely the result of two significant geologic events involving faulting due to horizontal extension or the stretching of earth's crust. The earlier of the two events is called detachment faulting and is primarily responsible for the rising of the Tortolita, Santa Catalina, and Rincon Mountains relative to adjacent valleys, the positioning of the rocks of the Tucson Mountains, and initial formation of the Tucson basin.

The most recent episode of regional faulting, termed **Basin and Range faulting**, modified the geometry of the basin produced by earlier detachment faulting and gave the region its present configuration. Basin and Range faulting is also due to a regional stretching of the crust; however faults that were active at this time are steeper than the earlier and therefore older, and more gently inclined detachment faults. During Basin and Range faulting,

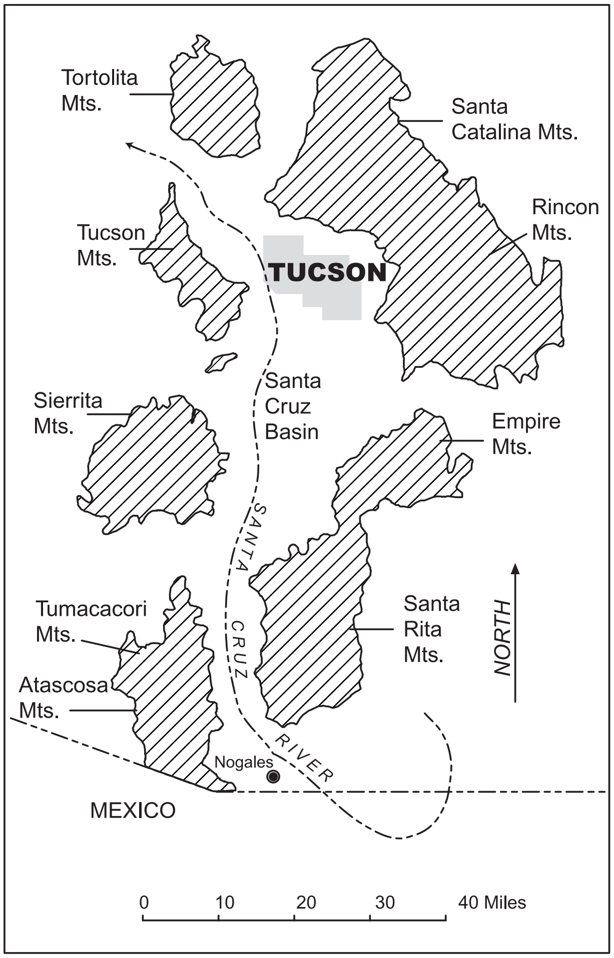


Figure 4. *Location map of Santa Cruz basin, surrounding ranges, and Santa Cruz River watershed. The Tucson basin forms the northern end of the Santa Cruz basin.*

the basins continued to drop relative to the adjacent ranges, which were uplifted. The Santa Cruz basin originally was a closed basin. This means that there was a lake or playa within the basin with no external drainage. The basin filled with sediment only in the last few million years, allowing the Santa Cruz River and its tributaries to drain to the north. The inexorable forces of weathering and erosion continue to modify the present landscape.

Hydrology (water) and Flood Hazards

Water is the lifeblood of any city and Tucson is no exception. Although the Central Arizona Project (CAP) canal is completed and now transports Colorado River water to the Tucson region, the saturated subsurface sediments of the Tucson basin have been the historical source of water for agriculture, industry, and residential needs. Drilling depths to water vary from approximately 100 feet to over 500 feet.

The Santa Cruz River is the major drainage in the Santa Cruz basin, and the river bed is the primary location of ground water recharge. The cumulative area of drainage of a river and its tributaries is called a **watershed**. The headwaters, and therefore the beginning of the Santa Cruz watershed, are actually in the Patagonia Mountains, which are to the southeast of the Santa Rita Mountains. From there, the Santa Cruz flows south into Mexico, then west before it turns north near Nogales and re-enters Arizona. It continues its northerly flow direction through Tucson's western edge, and ultimately enters the Gila River drainage southwest of Phoenix. Portions of the Santa Cruz River once experienced a perennial surface flow; however, with the lowering of the ground water level due to municipal, agriculture, and industrial pumping, it is now ephemeral. Surface flows occur only during heavy regional winter rains or briefly from intense, localized summer thundershowers that occur within the watershed's drainage system. The portion of the Santa Cruz River that is visible from "A" Mountain is dry approximately 300 days a year.

During floods, water may top the Santa Cruz's banks. In the floods of October, 1983, the banks of the Santa Cruz River were eroded and the stream channel migrated laterally at many locations, including near the Mission San Xavier del Bac. This was the result of particularly heavy flooding due to intense regional rain that lasted for several days. The entire Santa Cruz watershed received approximately 6" of rain over a 5 day period, and the drainage on the west side of the Santa Ritas, visible from "A" Mountain, experienced about 8" of rain. This caused a tremendous flow in the Santa Cruz River. Estimated flow rates under the Congress St. bridge during the peak of the storm was over 52,000 ft^3/sec. This was more than 4.5 times greater than the 1994 average daily flow of the Colorado River at Lees Ferry! The San Xavier (pronounced "have-ear") bridge is adjacent to the Interstate 19 crossing of the Santa Cruz River at Martinez Hill, and Martinez Hill is the small, dark hill visible in the middle distance toward the south. During the 1983 flood, the river bank eroded about 150 feet to the west from the end of the bridge giving the appearance that the bridge ended in the middle of the Santa Cruz River. The width of the Santa Cruz riverbed narrows significantly from the area near Martinez Hill and the Mission San Xavier del Bac to the Congress Street bridge in downtown Tucson. This funnel effect increases the velocity of the surface runoff as it passes through the metropolitan center. Efforts have been made to stabilize portions of the river banks by means of soil cement to prevent lateral channel migration.

Rainwater and snow melt from the surrounding mountains are the source of the valley's ground water supply. The main recharge arteries are the major drainages: the Santa Cruz River on the west side of the Tucson Basin, the Pantano Wash on the northeast side, and the Tanque Verde Wash and Rillito River on the northern side of the Basin. The runoff in these drainages percolates downward from river beds and the water slowly migrates through the sand and gravel. Recharge also occurs along the mountain fronts. Gravity is the primary mechanism that controls the snails-paced movement of subsurface water in the voids between grains. The top of the saturated sediments, termed the **water table**, also roughly mimics the land surface. Ground water movement is approximately in the same direction as surface flow, which in Tucson is northwesterly.

Geologic Features

To the south, Interstate 19 appears as a straight line towards Nogales, Arizona and Nogales, Sonora, Mexico (Fig. 5). The large mountains on the skyline to the left (east) of I-19 are the Santa Rita Mountains. The lower hills at the northern end of the Santa Rita Mountains are the Empire Mountains. The Santa Rita and Empire Mountains are composed of a complex sequence of igneous, sedimentary, and metamorphic rocks of various ages.

The highest peak in the Santa Rita Mountains is Mt. Wrightson (9,453 feet) and the slightly lower peak to the right (west) is Mt. Hopkins (8,585 feet). Just to the north (this side) and near the saddle (low area) between these peaks is the mouth of Madera Canyon. It is a popular recreation area for hikers and bird-watchers. Rock debris that washes out of a canyon and forms a sloping wedge of sediment that in map view resembles a piece of pie, is called an **alluvial fan**. The tan-colored alluvial fan shape at the mouth of Madera Canyon is visible to the south. When several alluvial fans merge to form a sloping surface at the front of a mountain range, the resulting feature is called a **bajada**. The slopes of the northern and western portions of the Sierrita Mountains are an excellent example of this feature.

There are also several ancient reminders that, although the Tucson region has few earthquakes compared to regions such as California, southern Arizona has experienced significant earthquakes in the past and has the potential for earthquakes in the future. Evidence of earthquakes in the form of low, linear escarpments, called **fault scarps**, where a fault has ruptured the surface during an earthquake, is present in the alluvial fan near Madera Canyon. Fortunately for the valley's inhabitants, all evidence suggests that these faults have not produced earthquakes for thousands of years and probably it will be thousands of years more before an earthquake occurs because of movement along them.

The Santa Rita Mountains host a number of ore deposits, and among the metals that have been recovered are copper, gold, lead, zinc, molybdenum, and silver. There are active placer gold mines in the Santa Rita Mountains, and the area remains a favorite region for the recreational prospector. Placer mining involves separating gold from loose sediments. The whitish scar visible near the northern end of the range is a marble quarry. Marble is a metamorphic rock formed from the heating and recrystallization of limestone deep in the earth. The marble from this quarry is used in landscape and industry markets.

The low, symmetrical dome-shaped mountains in the skyline to the west (right) of Interstate 19 are the Sierrita Mountains. They contain a complex sequence of igneous, sedimentary, and metamorphic rocks of different ages. The man-made feature on the east side is the stair-stepped shape of waste rock, called tailings, from the open-pit copper mines located there. Mines in this area of the Sierrita Mountains have been producing metals since the late 1800's. During the past 100 years over 8 ***billion*** **pounds** of copper, 75 ***million*** **pounds** of lead, 132 ***million*** **pounds** of zinc, 290 ***million*** **pounds** of molybdenum, and 56 ***million*** **ounces** of silver have been produced from the mineralized rock.

In the middle distance and this side of the Sierrita Mountains lie a group of dark and seemingly disconnected hills collectively named the Del Bac Hills. The Mission San Xavier del Bac's white buildings stand out in contrast to the black volcanic rocks of the Del Bac Hills. The larger hill to the right of the mission is Black Mountain. The smaller hill to the left of the mission and adjacent to Interstate 19 is Martinez Hill. The Del Bac Hills are similar in age, about 25 million years, and composition to Tumamoc Hill and Sentinel Peak ("A" Mountain). The other low relief hills in that area are the southern extension of the Tucson Mountains, whose lighter-colored volcanic rocks erupted about 70 million years ago.

One might infer that since the alluvium (boulders, gravel, sand, and clay) laps up against the irregular base of the southern Tucson Mountains, the subsurface contact between the down-dropped basin and the mountain block must also be irregular. Actually, the alluvium is just a thin veneer of sediment that buries an erosion surface of the mountain block. A

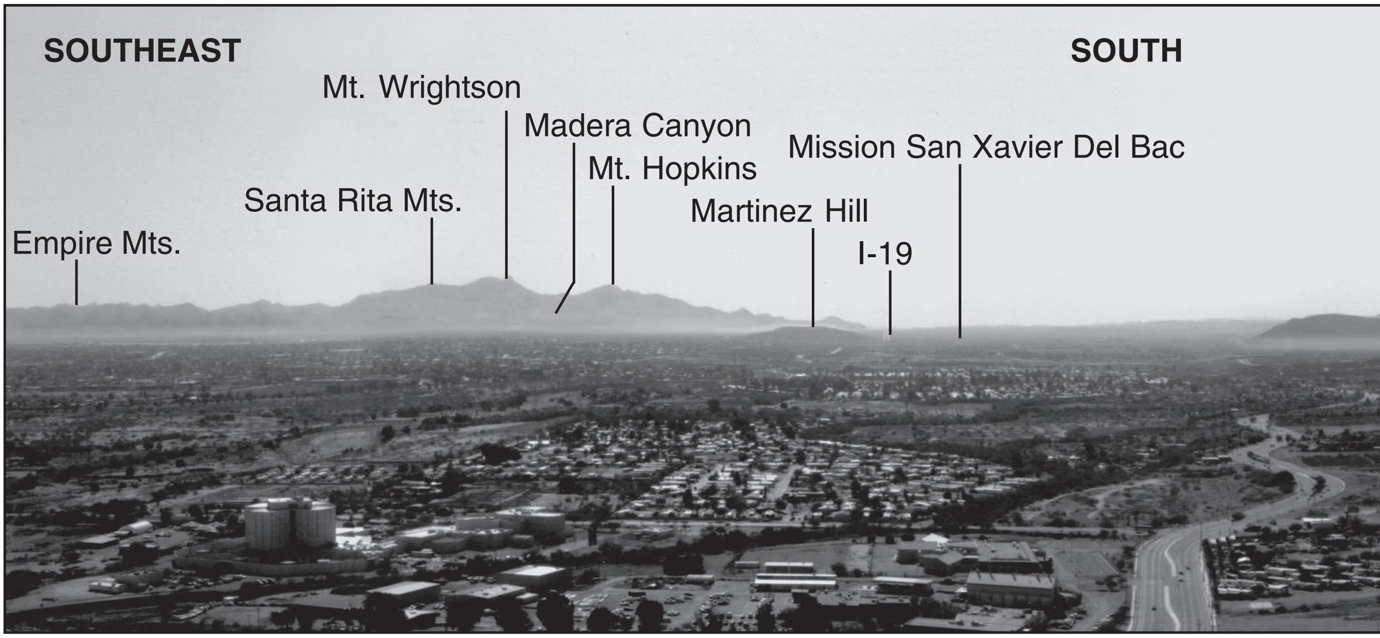


Figure 5. *Panorama from top of "A" Mountain. View is south toward Mexico.*

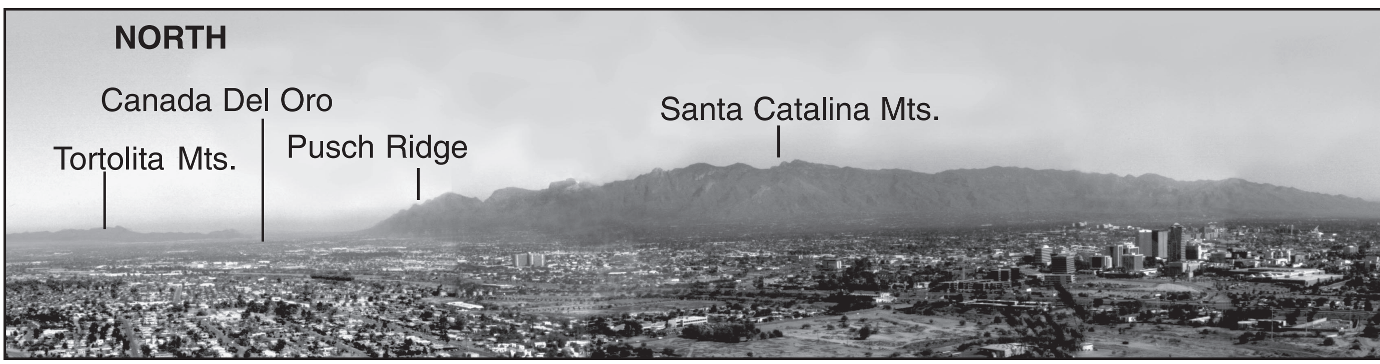
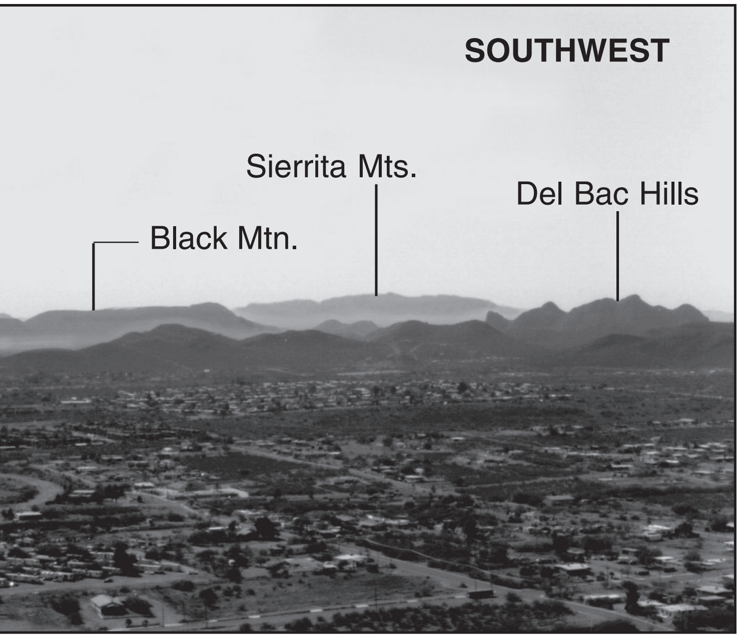


Figure 7. *Panorama from top of "A" Mountain. View is northwest (Tortolita Mountains), north (Santa Catalina Mountains), and east (Rincon Mountains).*

gently sloping bedrock surface under this thin veneer of alluvium can extend up to several miles from the embayed alluvium-bedrock contact. This is called a **pediment** (Fig. 6). At some distance from the exposed bedrock the basin may become much deeper. The Del Bac Hills appear as small islands surrounded by sediment. They are part of the mountain block, however. The actual Basin and Range fault that controls the separation between the Tucson Mountains block and sediments of the deep Tucson basin is buried just to the left (east) of Martinez Hill.

The Santa Catalina and Rincon Mountains encompass the northern and eastern portions of the Tucson basin, respectively (Fig. 7). They are also composed of intermixed igneous, sedimentary, and metamorphic rocks. These mountains are commonly referred to as Catalina-Rincon Mountains because the two connected ranges contain similar rocks and were formed by similar processes and events. To the east are the Rincon Mountains. The high, round mountain in the skyline is Mica Mountain (8,666 feet) and the peak to the right is Rincon Peak (8,482 feet). The saddle to the left (north) of Mica Mountain is Redington Pass, and the low hill to the left (north) is Agua Caliente Hill. The Santa Catalina Mountains tower to the north of the Tucson metropolitan area. The highest peak, Mt. Lemmon (9,157 feet), is also the highest peak among the ranges that surround the Santa Cruz basin.

Uplift of the Santa Catalina-Rincon Mountains involved the two earlier mentioned episodes of faulting caused by crustal extension. The first episode occurred roughly 35-20 million years ago and



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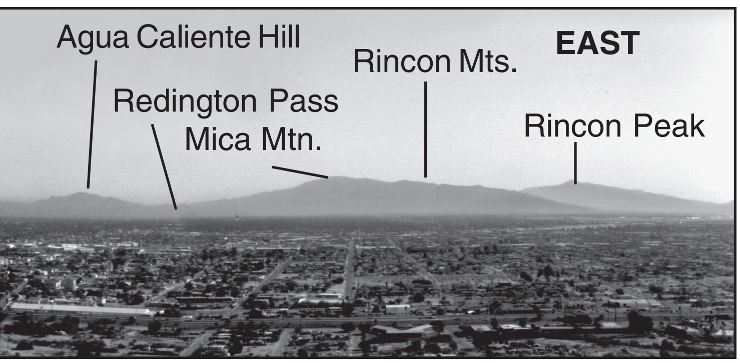

Figure 7.

involved a style of faulting termed **detachment faulting**. In essence, gently sloping faults were active during this episode. As the crust stretched and thinned, the rocks below the plane of the fault were drawn out from under the rocks above the fault plane. The horizontal separation involved may have approached 15-20 miles. The rocks under (below) the fault plane, buried in excess of 6 miles below the existing surface at that time, were quite hot and, consequently, deformed plastically, like stretching taffy very slowly. Conversely, the cover rocks above the fault plane were closer to the surface and therefore under less confining pressure and heat. These rocks, when deformed, would fracture and shatter. During the 10 to 15 million years of faulting and deformation, the rocks above the gently inclined fault plane were "detached" from the underlying rocks. During faulting, confining pressures of rocks below the fault were lowered and the deeper-level rocks began to arch upwards. As these once deeply buried rocks inched closer to the surface, they also began to fracture. Subtle evidence for both the deeper formed plastic deformation and the shallow related brittle deformation is preserved in the rocks now exposed along the southern reaches of the Catalina Mountains and the western edge of the Rincon Mountains. The tilted rocks of the Tucson Mountains were at or near the surface and were involved in this episode of crustal stretching and thinning. Geometric reconstruction would place the Tucson Mountain rocks originally somewhere in the vicinity of the Catalina foothills.

The second and more recent episode of faulting, also caused by crustal stretching, is named **Basin and Range** faulting, and changed the configuration of the Tucson region (Fig. 6). This style of faulting, which in this region began approximately 15 million years ago and was concluded by about 5 million years ago, involved much steeper faults that are now covered by eroded rock debris (alluvium). A classic example of Basin and Range faulting is the formation of the Cañada del Oro Valley that lies between the Santa Catalina and Tortolita Mountains. The view from the north side of "A" Mountain is along the length, also termed the axis, of the Cañada del Oro. The steep, Basin and Range age fault at the east edge of Oro Valley, named the Pirate Fault, lies largely buried along the western foot of the Santa Catalina Mountains. Another Basin and Range fault on the west side of the Cañada del Oro valley might be buried by alluvium between Highway 77 and the low relief Tortolita Mountains. The down-dropped and possibly tilted block of bedrock, therefore, lies buried under the Cañada del Oro valley between the Santa Catalina and the Tortolita Mountains.

The westerly view is of the northwest trending Tucson Mountains. As in most of the ranges in southern Arizona, they are composed of igneous, metamorphic, and sedimentary rocks of different ages. Granitic rocks are present in the northern reaches of the range, and sedimentary rocks are preserved on the western flank.

Volcanic rocks dominate the view west from "A" Mountain, and the ages of these rocks are approximately 25 million years for "A" Mountain and Tumamoc Hill rocks and about 70 million years for the rocks visible along the western skyline. Recent studies interpret the volcanic rocks near and along the west skyline as being formed from a caldera-forming eruption, or a series of closely spaced eruptions. A **caldera** is

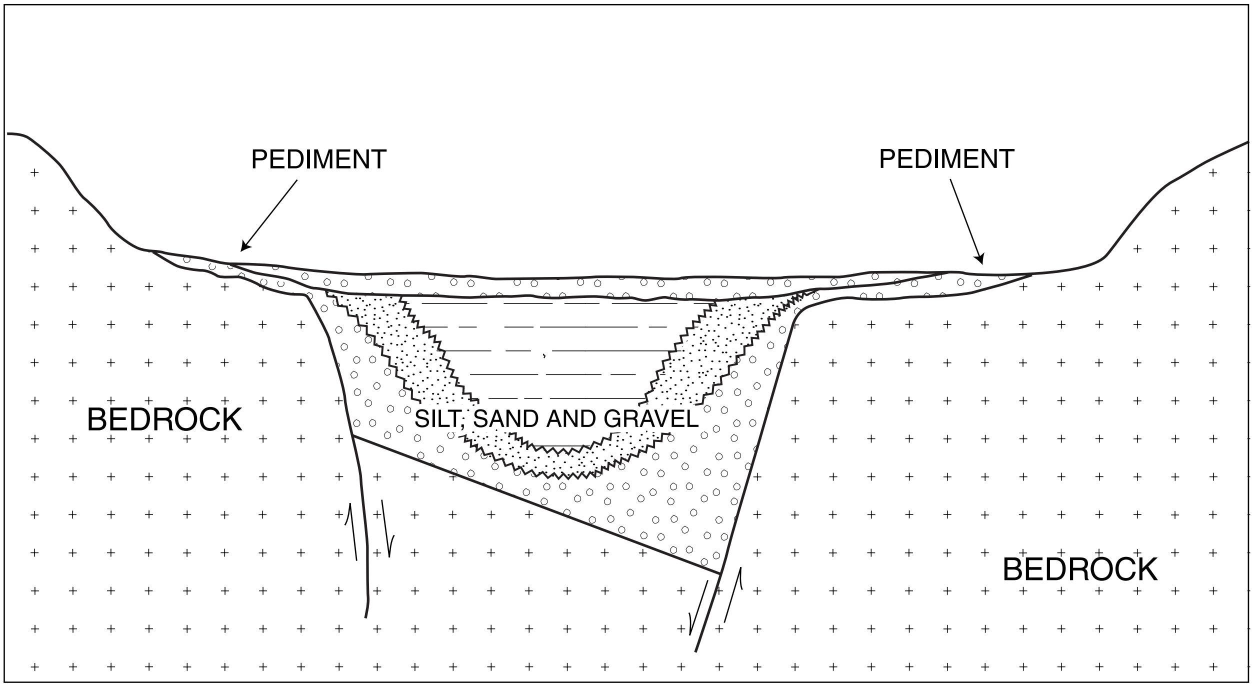

Figure 6. *Simplified cross-section of Basin and Range. No scale.*

a feature created when a volcano collapses into the top of a magma chamber as the chamber expels magma during a volcanic eruption. Crater Lake in Oregon, for example, is a young caldera. Wasson Peak (4,687 feet), northwest of “A” Mountain, is the highest peak in the Tucson Mountains and is composed of rocks formed during the caldera-forming event. The Tucson Mountain caldera-forming eruption is estimated to have occurred about 70 million years ago, which is just before the time of the dinosaurs’ demise approximately 65 million years ago. It is also approximately the same time as the formation of the copper deposits that are currently being mined in the Sierrita Mountains. The original caldera shape has been obliterated by faulting and erosion.

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